Chemical Evolution on the Scale of Clusters of galaxies

Alvio Renzini, with the assistance of Stefano Andreon

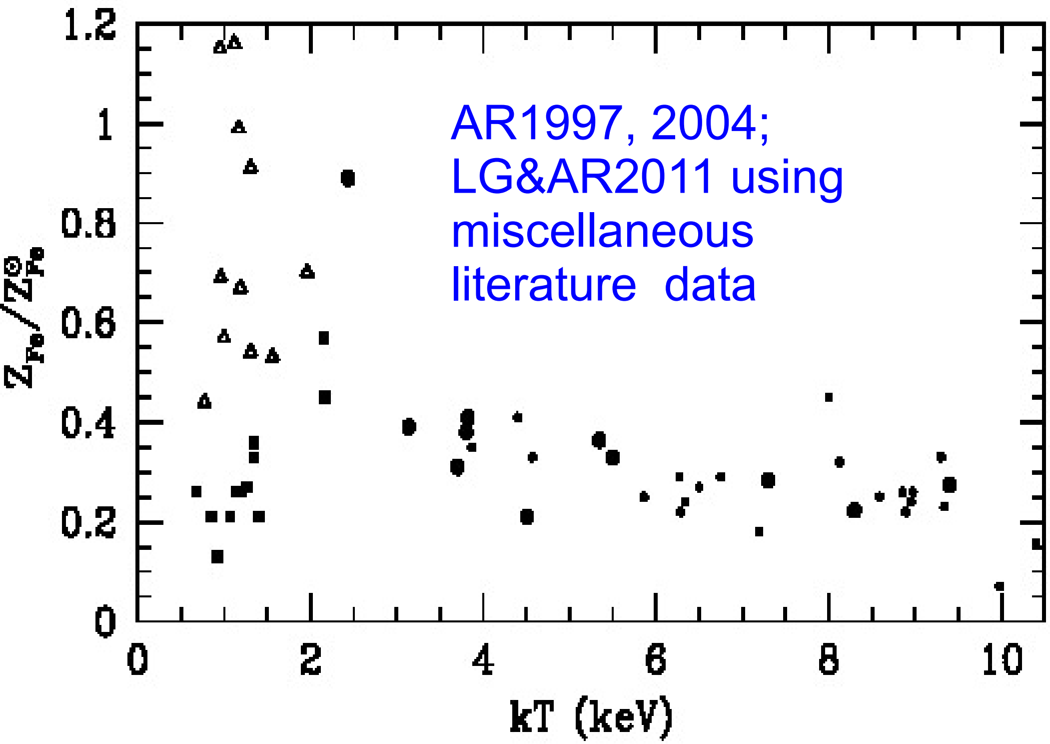
Outline:

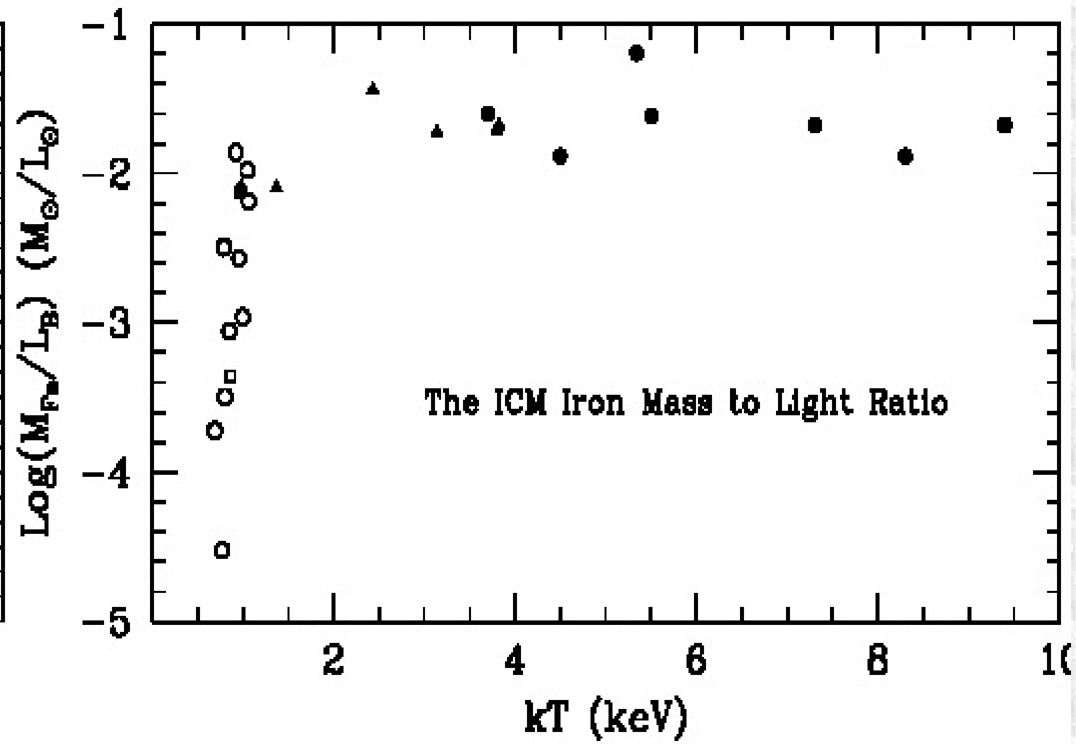
- ☆ My (simplistic) view of cluster chemistry
- ☆ Possibly crumbling this view: the cluster conundrum posed by Stefano Andreon
- ☆ An empirical estimate of the yield and an integral constraint on the "loading factor"
- ☆ No conclusions

Chemical abundances in galaxy clusters: a theoretical approach

F. Matteucci [1,2] and G. Vettolani [3]

My Simple/istic View of It





$$(\mathrm{Fe}M/L)_{\mathrm{cl}} \simeq (4-6)\times 10^{-4} \times (M_{\mathrm{ICM}}/L_{\mathrm{B}})h_{70}^{-1/2} + 1.1\times 10^{-3}\frac{M_*}{L_{\mathrm{B}}}h_{70},$$ = (0.016—0.021) $M_\odot/L_{B\odot}$

$$\frac{Z_{\mathrm{ICM}}^{\mathrm{Fe}} M_{\mathrm{ICM}}}{Z_*^{\mathrm{Fe}} M_\star} \simeq (1.6-3.3)\times h_{70}^{-3/2}$$

There are more metals outside galaxies than within them (in stars)

And how to make it ...

- For a "Salpeter-diet" IMF: 7 CC SNe and 1-2 SNIa's every 1000 $M_\odot$ into stars
- From CC SNe: $\langle M_{Fe} \rangle_{CC} = 0.06\ M_\odot$ of iron (empitical!)
- From each SNIa: $\langle M_{Fe} \rangle_{Ia} = 0.7\ M_\odot$ of iron

➔ So, $7\times0.06 + (1\text{-}2)\times0.7 = (1.12 - 1.82)\ M_\odot$ of iron every 1000 $M_\odot$ into stars (Yield $\simeq$ 1-2 $Z^{Fe}_\odot$)

1000 $M_\odot$ of stars ~ 11 Gyr ago are ~600 $M_\odot$ of stars today and their B-band luminosity is ~83 $L_\odot$ (from Maraston05 SSP models)

➔ Predicted $M_{Fe}/L_B = (1.12 - 1.82)/83 = (0.013\text{-}0.022)\ M_\odot/L_{B\odot}$

Observed = $(0.016\text{-}0.021)\ M_\odot/L_{B\odot}$

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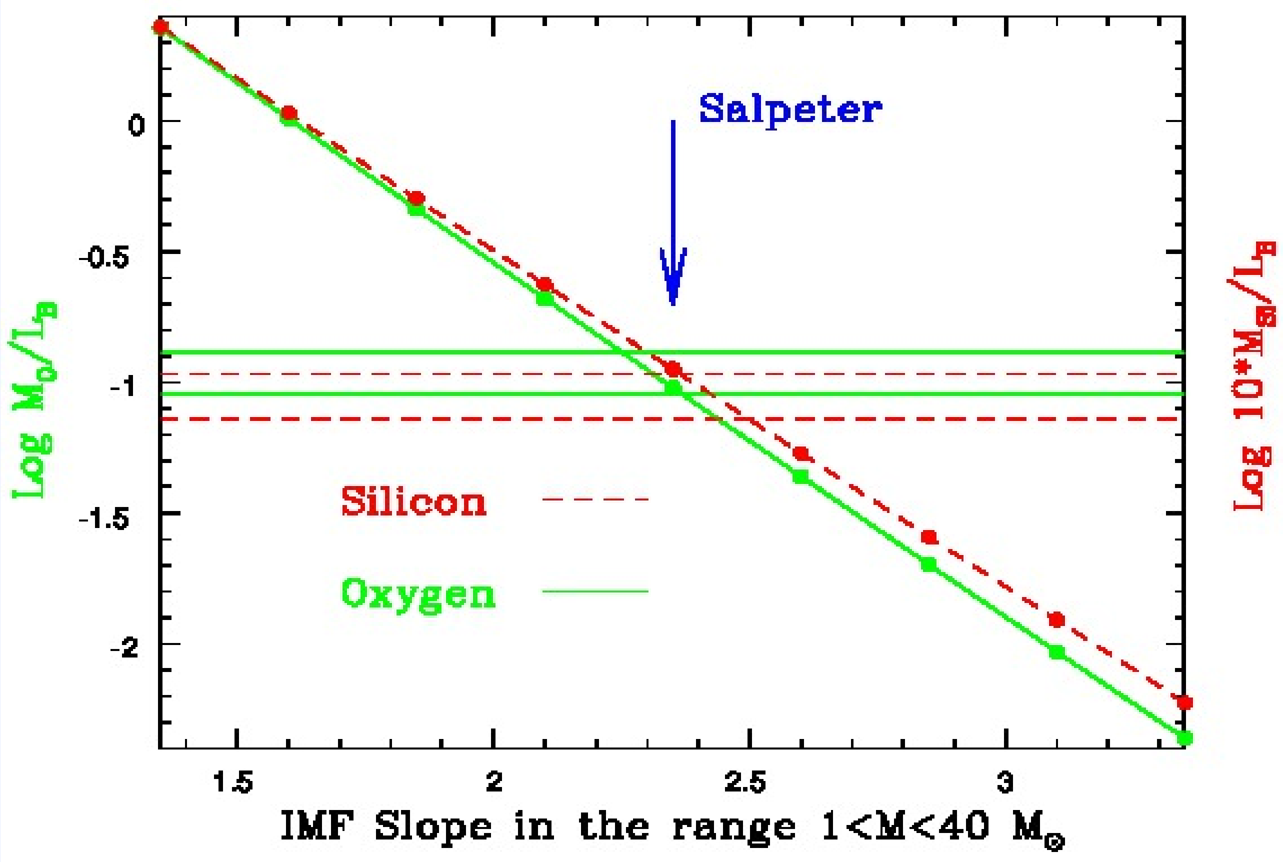
Further Reassuring the Simple/istic View

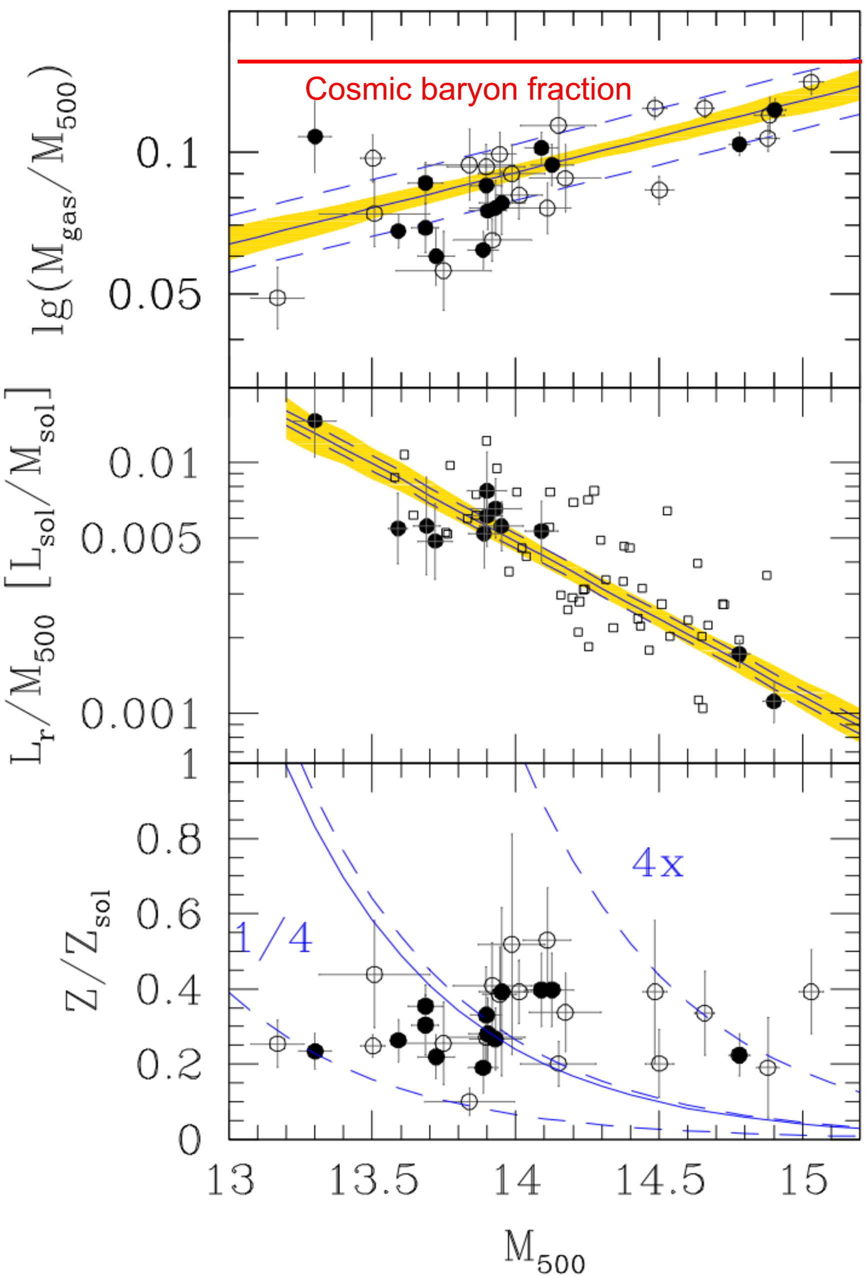
Happy 80th birthday postcard to E. Salpeter



AR2005 + LG&AR2011 Using Woosley & Weaver 1995 Nucleosynthesis

BUT ➔

The New Conundrum



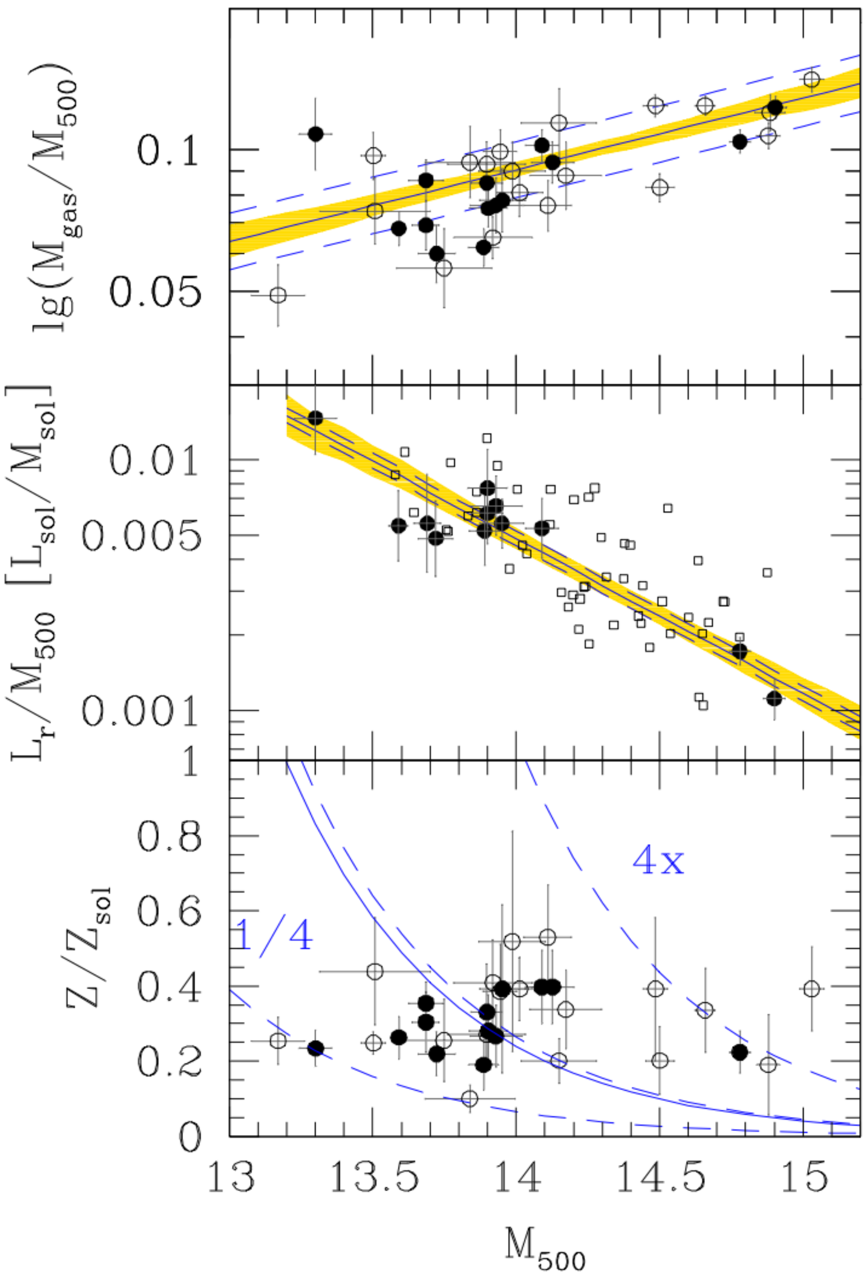
- ● "Best measured" 12 clusters with M_{gas}, M_{500} and Z from Viklinin+2007 & Sun+2009 and L_r from Andreon 2010, 2012
- ○ M_{gas}, M_{500} and Z from the same sources, but No L_r available.
- □ M_{200} (NOT M_{500}) "caustic masses" from Rines & Diaferio 2006; $L_{r(200)}$ from Andreon 2010

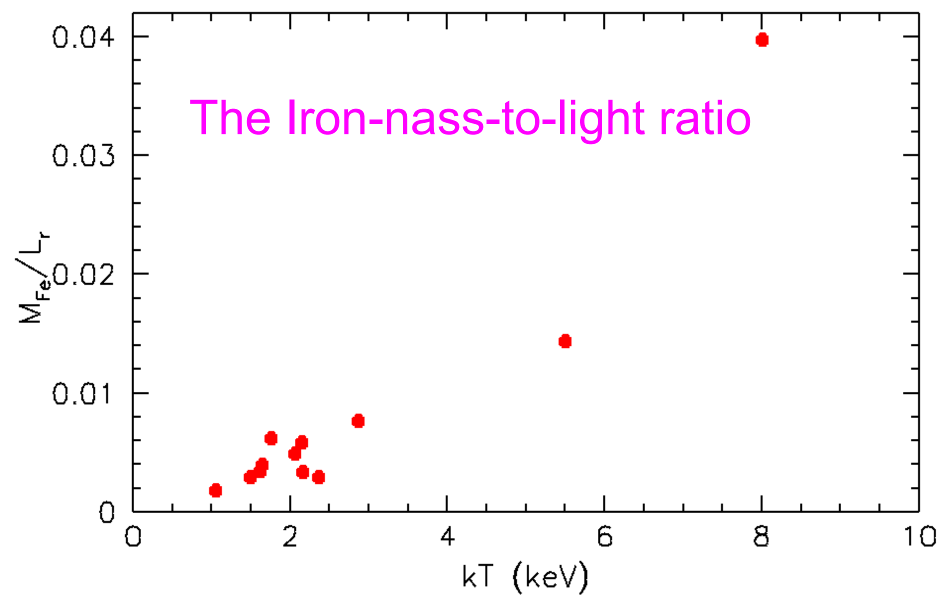
Andreon's real Nightmare

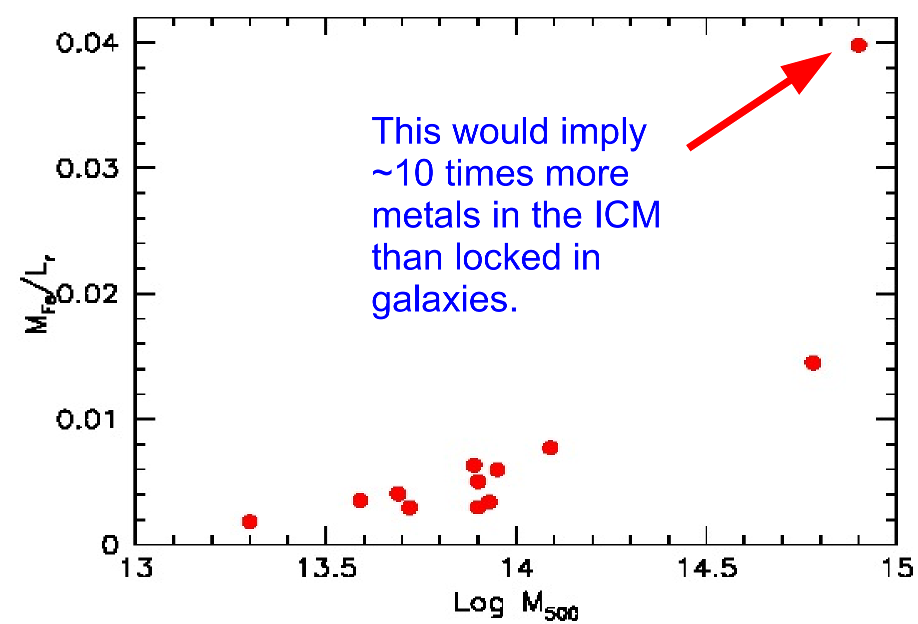
See also Conzalez et al. last tuesday on astro-ph

The New Conundrum

Andreon 2013

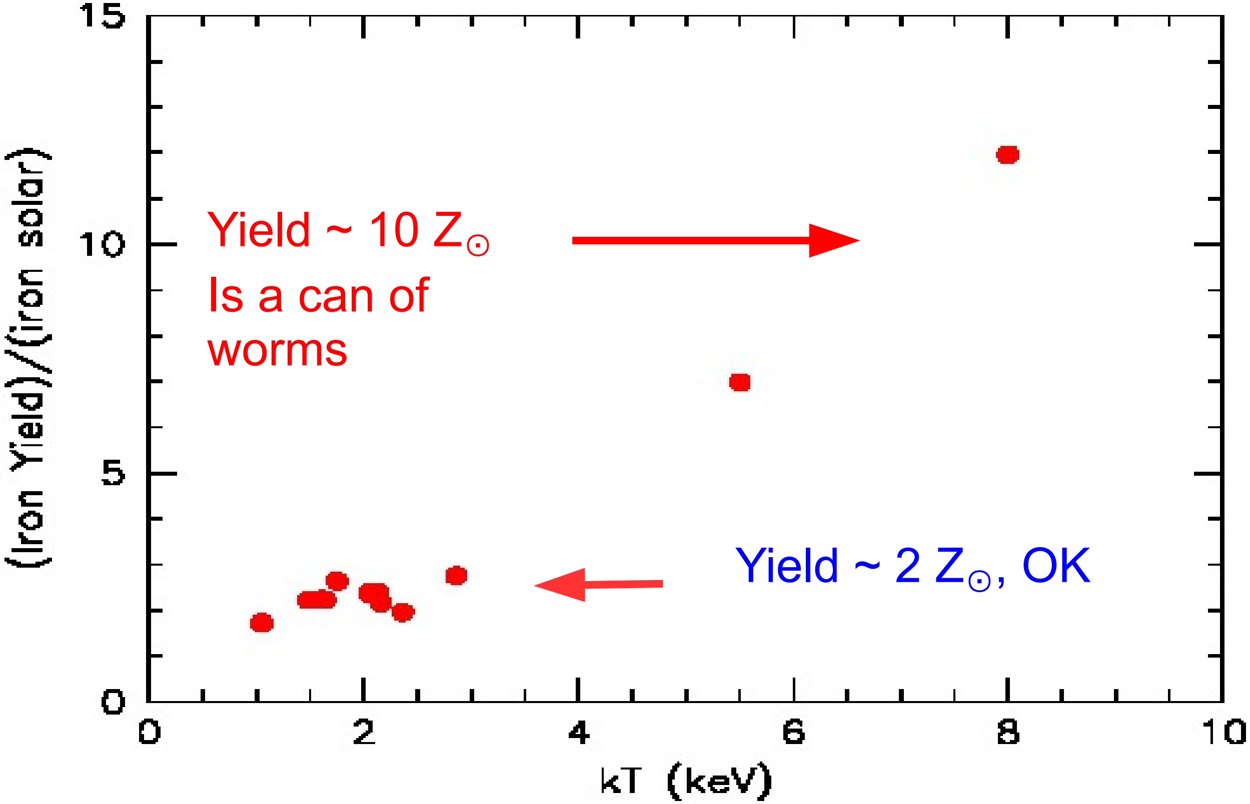






The New Conundrum (cont.)

Yield = $Z^{Fe}_{\odot}(M^* + 0.3xM_{ICM})/M^*$



All possible Solution of The Conundrum are Very Ugly!!

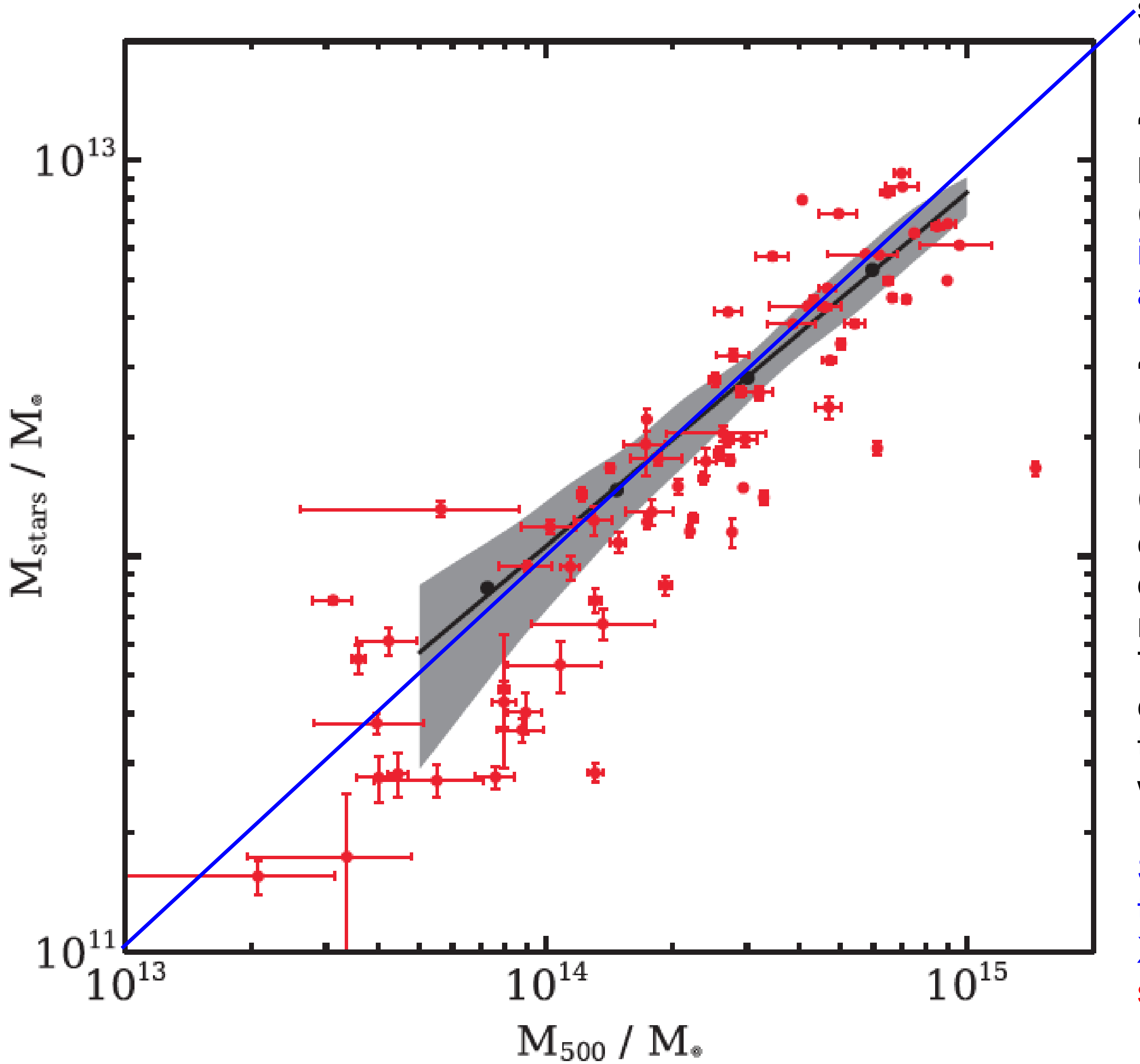
1) The slope of the IMF above ~1 $M_\odot$ tightly correlates with the present mass of the clusters, i.e. Star-forming clouds at z~3 should know in advance the mass of the clusters in which their products will be hosted >~ 10 Gyrs later. Yield = $F(M_{500})$ ....

2) In the most massive clusters there are ~5 times more stars out of galaxies than inside them ($L_{ICL} \sim 5\ L_{gals}$)

3) The Yield is universal and ~10 $Z_\odot$ () but only the most massive clusters have retained ~ all the metals, most metals (and gas) lost by other clusters.

4) There is a problem in the measurement of L_r in Andreon 2010 or of M_{gas} and/or M_{500} in Vikhlinin+2006 etc.

Strange Agreement .....



Budzynski et al 2013: " We find that the stellar mass fraction depends only weakly on total mass and that the contribution of ICL to the total stellar mass fraction is significant (typically 20-40 %)."

"The star formation efficiency (fraction of cosmic barions now into stars) is relatively low at 8% cent (14%)"
i.e., my cosmic favorite ~10% in clusters and field alike.

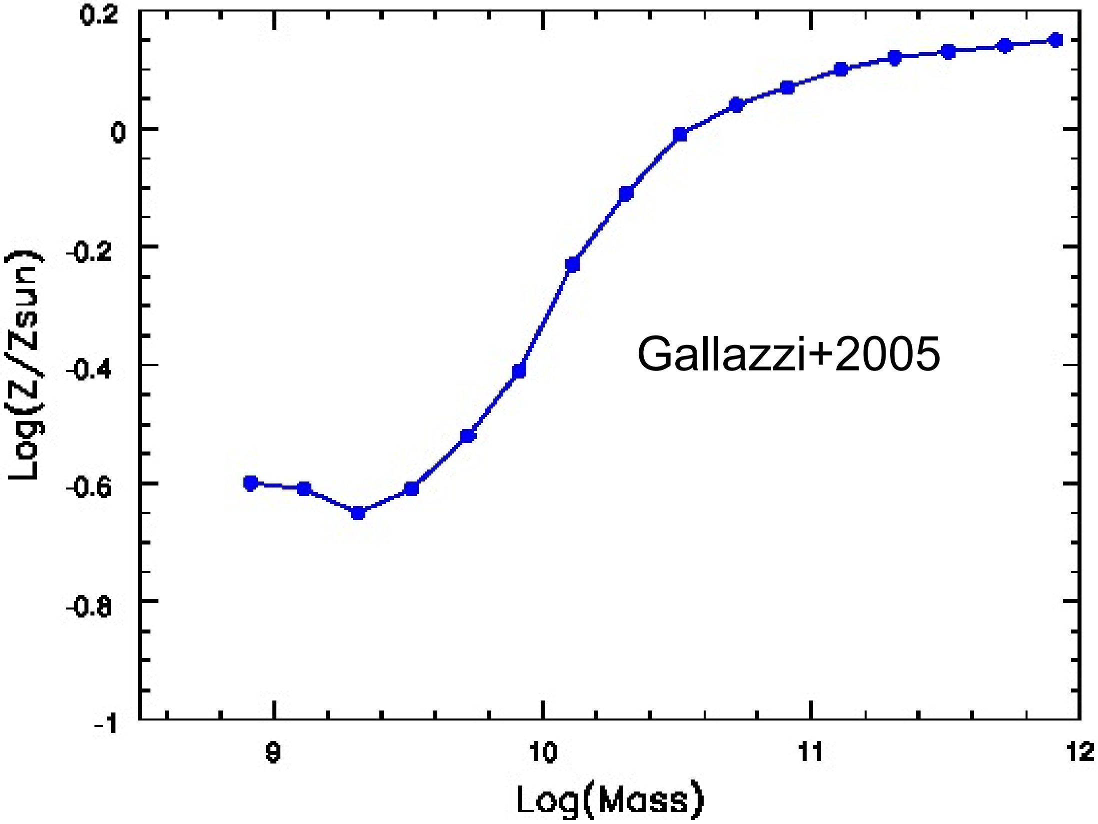
"Reassuringly, we find that excellent agreement (with low scatter) is achieved at all masses with the results of A10 if we adopt the same aperture as A10 (i.e., use their $\mathbf{r}_{200}$) and make a self-consistent comparison ... This agreement implies that the differences ... are due to differences in the total mass estimates, not in the stellar mass estimates ... The origin of this difference is unclear. To date, the caustic mass methodology has not been extensively tested on cosmological simulations so it is unclear to what extent the masses are biased. "

So, is the conundrum solved? Maybe not: M500 for the most massive clusters in Andreon 2013 are from X-Rays, not "caustic masses" ...: the conundrum is still alive.

Another empirical estimate of the Yield

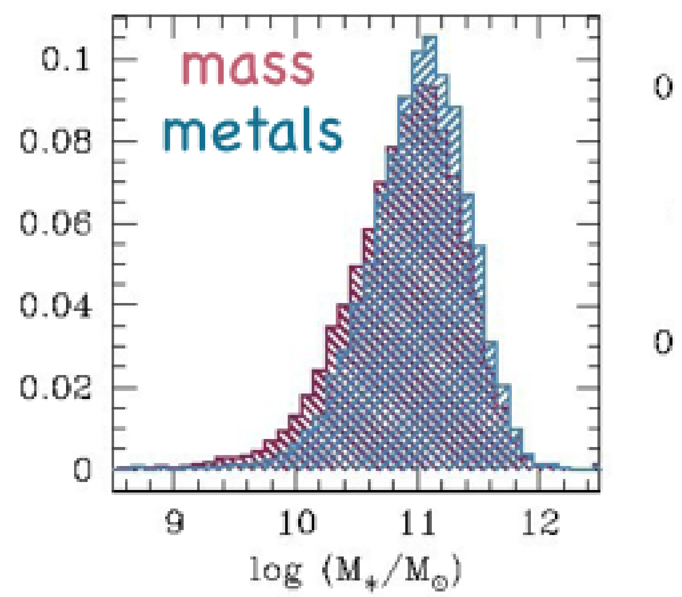
I want to see how galaxies have contributed to metal production and ejection

All SDSS Galaxies, SF + Quenched

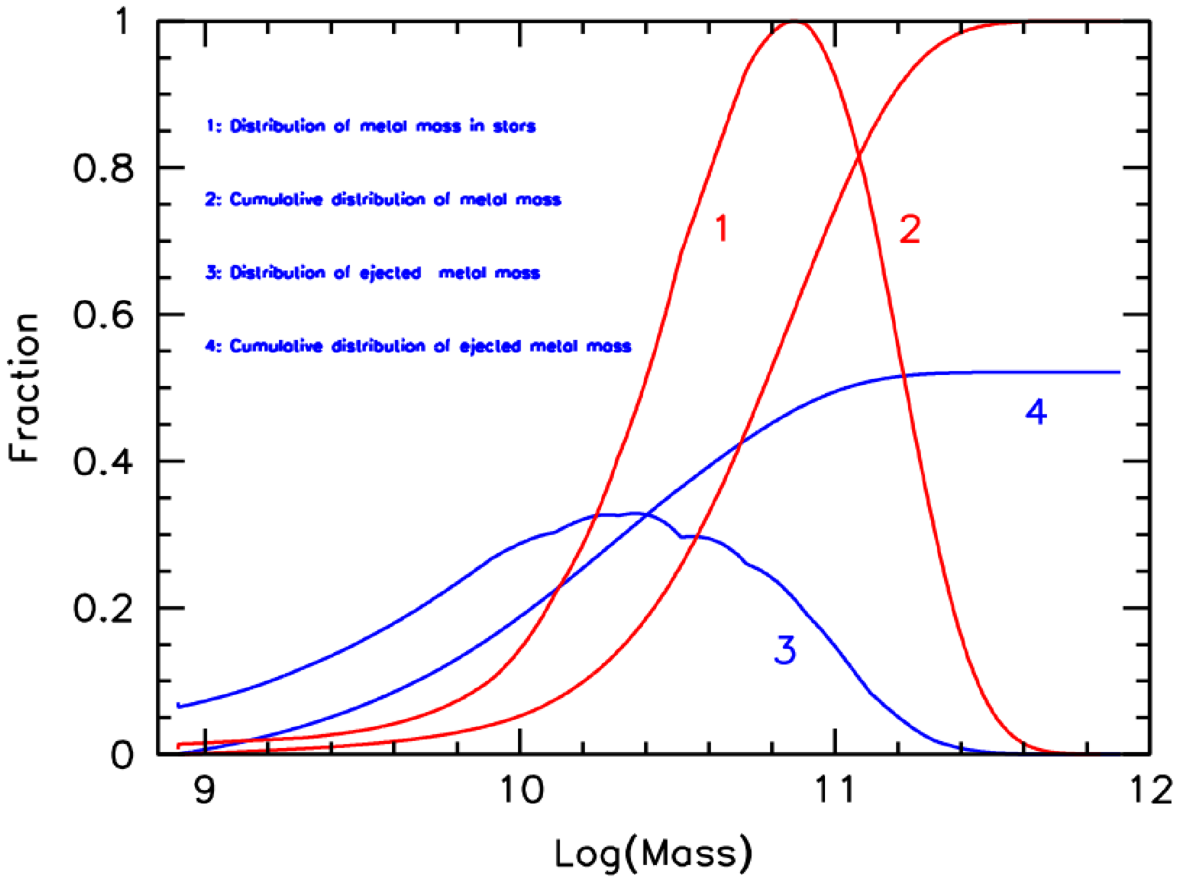


Z_{max} = 0.028

Gallazzi+2008

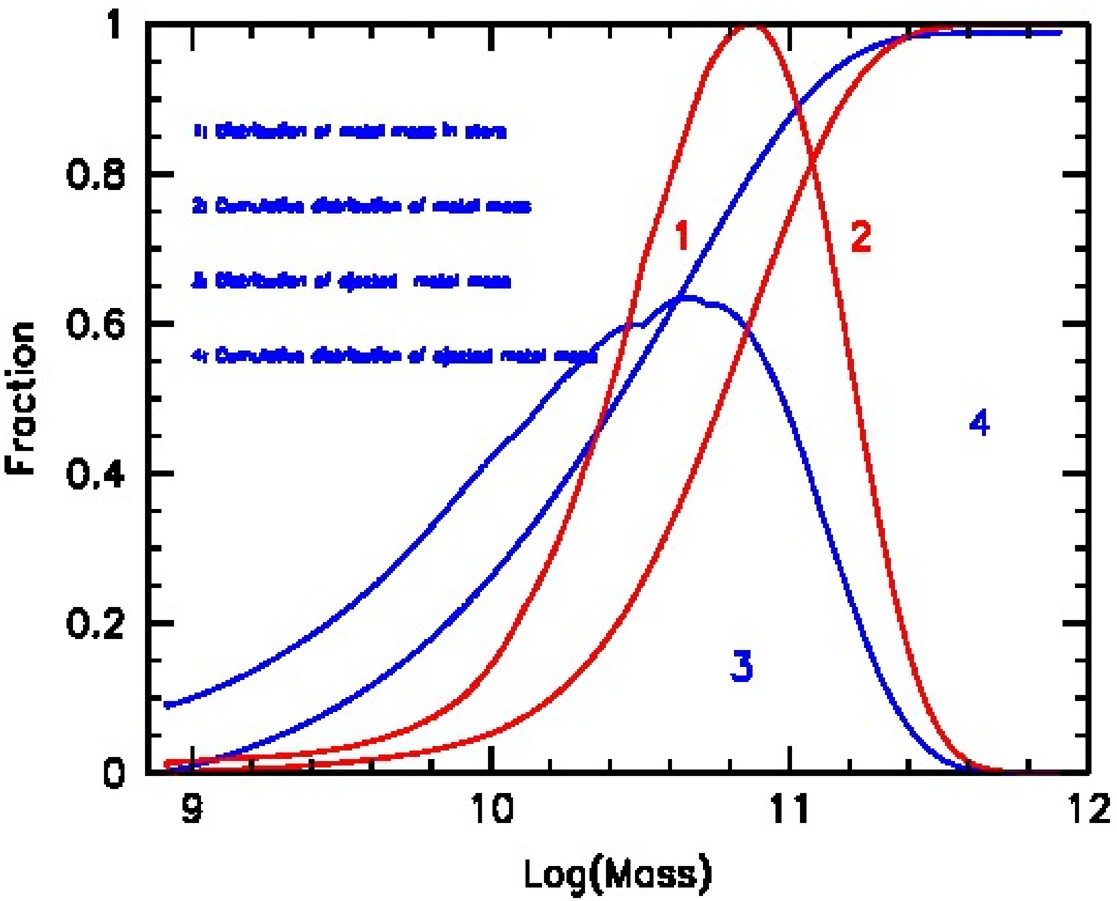


- Assume yield is a universal constant (independent of age, metallicity, mass)
- Mass of metals now in stars: $M^*_Z = \int M\, Z(M)\varphi(M)dM$ with $Z(M)$ from Gallazzi+2005 and $\varphi(M)$ from SDSS as in Peng+2010
- Mass of metals NOT in stars, assuming most massive Galaxies don't lose metals: $M^{NOT*}_Z = \int M\, [Z_{max} - Z(M)]\varphi(M)dM$ with $Z_{max} = 0.028$



With these assumptions ~2/3 of the metals are still inside stars in galaxies and only ~1/3 have been ejected into the IGM/ICM

- To achieve a 50-50 share between stars and IGM/ICM we need Z_{max} = ~ 0.0366 or Yield = ~1.8 $Z_{\odot}$



Below ~2 10^{10} $M_{\odot}$ galaxies have lost more metals than they have retained.

Above 10^{11} $M_{\odot}$ galaxies have contributed just ~10% to metals in the ICM/IGM

An integral constraint on the loading factor = (galactic wind rate)/SFR

Work in progress ....


Thank you!